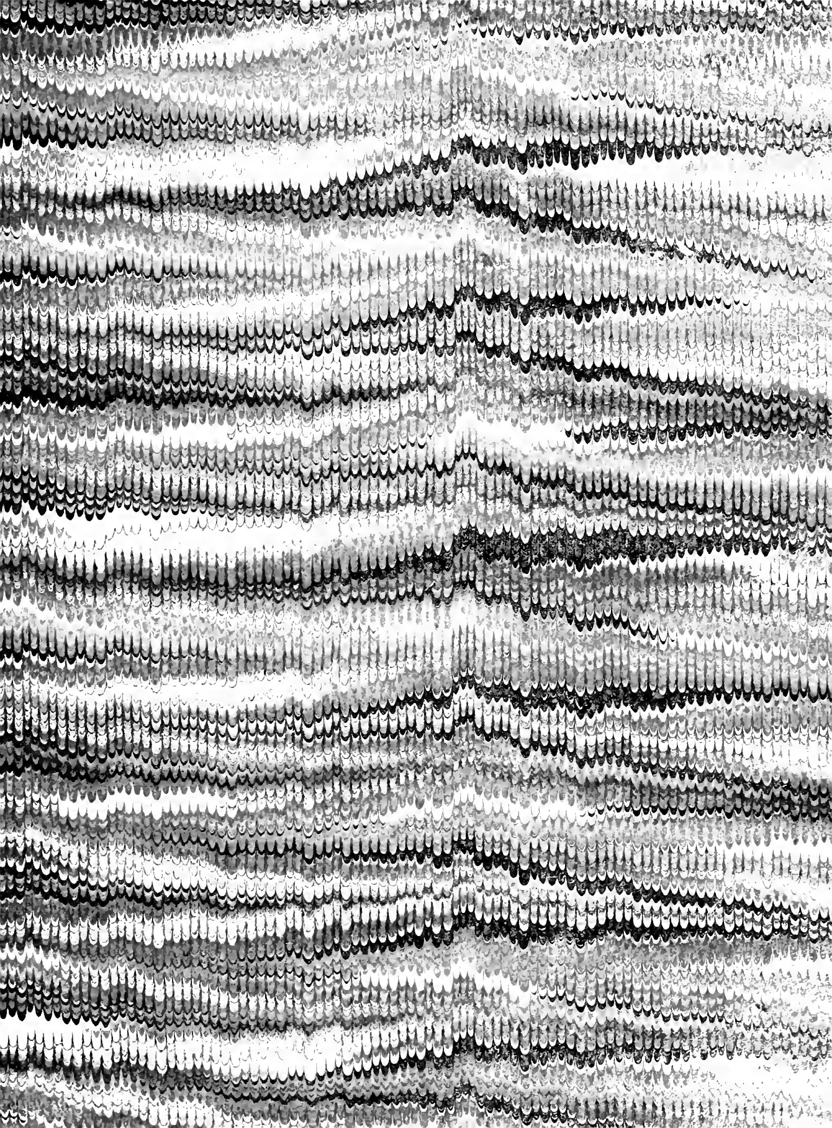

SELECTIVE REFLECTION IN THE INFRA-RED SPECTRUM.

By

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DISSERTATION
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SELECTIVE REFLECTION IN THE INFRA-RED SPECTRUM.

Certain substances which transmit a large percentage of the incident radiation in the visible portion of the spectrum, reflect strongly in the infra-red. Of these, one of the most noteworthy is quartz. It has been shown by Professor E. F. Nichols* that in the neighborhood of wavelength 8.5μ the reflection from a quartz surface is 20 or 30 times greater than in the other parts of the spectrum, and that, consequently, in the spectrum of rays after three successive reflections these waves will lose little in intensity, whereas, those lying on either side of this value will be reduced in the ratio of $(20)^3$ or $(30)^3$ to 1. The spectrum, then, after three reflections will contain practically only the radiation of wavelength $\lambda = 8.5\mu$, and this in measurable quantity. Rubens and Nichols**, and Rubens and Aschkinass*** have employed

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* E. F. Nichols, Physical Review, Vol. IV, p.297,(1897).
** Rubens and Nichols, Annalen, 60, pp.418 and 430 (1897).
*** Rubens and Aschkinass, Annalen, 65, p. 241, (1898).

this method, commonly known as the method of "Reststrahlen", for the detection of waves of great length in the infrared.

In the work which has been done by these investigators it has been assumed that the positions of the reflection maxima and the absorption maxima coincide, and dispersion formulae have been used in order to predict the positions of the reflection maxima. This assumption is not entirely justifiable, and the agreement between the calculated and the observed values for the very long waves is not sufficiently conclusive. One of the objects of this research was to accumulate facts which might possibly throw some light upon the problem. The data, however, in regard to the dispersion of substances available for experiment are too limited to enable one to draw any conclusions. It is hoped, nevertheless, that the few facts here added may at some time prove useful in the solution of the problem.

Wavelength measurement by the method of "Reststrahlen" is perfectly simple, and will be explained after the apparatus has been demcribed. The following is a list of the substances which have been studied by others and the wave-

lengths of their reststrahlen measured by this method; quartz, fluorite, sodium chloride, sylvine, mica, marble, sodium bromide and calcium bromide. A detailed discussion of these is to be found in the papers referred to above. Each substance is characterized by well marked maxima which occur in the grating spectrum after three or more successive reflections. Fourteen other crystalline compounds have been examined by the writer. Seven of them, viz. potassium dichromate, copper sulphate, tartaric acid, ammonium chloride, potassium sulphate, potassium bisulphite and potassium ferrocyanide, show unmistakable maxima at various parts of the spectrum. A few words with reference to each of these will be said after the apparatus has been described.

Apparatus.

Radiometer. The radiometer was selected for this work because of the great difficulty in working in this laboratory with an instrument which is highly sensitive to small changes in the electric or magnetic conditions. This reason has barred the use of bolometer and thermopile, while the radiomicrometer, the only other instru-

ment which can be used in work of this kind, for equal sensitiveness, is not so reliable as the radiometer. The latter instrument, undoubtedly the best for infra-red work in this laboratory, is objectionable on account of the absorption due to the fluorite plate. Above 11 practically no radiation gets through. With it, therefore, measurements cannot be made on waves whose wavelengths exceed this value.

The instrument here described is in almost every respect similar to the one used by Professor Nichols at the Yerkes Observatory in the summer of 1900*. Two vertical sections at right angles to each other are shown on the following page. The scale of the diagram is one half natural size for all parts except the suspension, H, which is approximately natural size. Tube A was cemented to a drying tube containing phosphorus pentoxide with a Toepler mercury pump. On the frame supporting the pump was also placed a McLeod gauge which gave readings consistent to .001 of a millimeter of mercury. The openings at the lower end of the brass case R, three in number,

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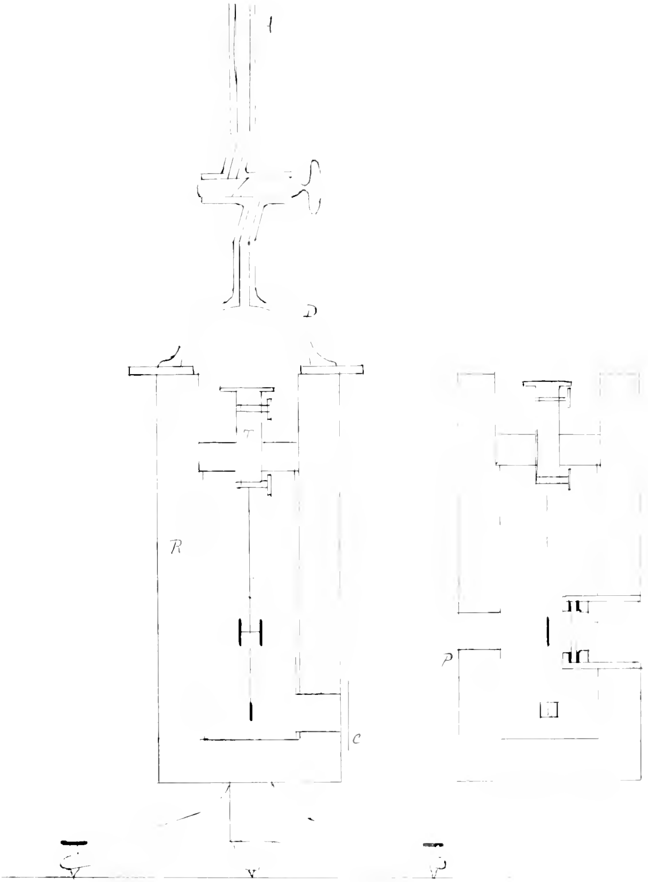
* Astrophysical Journal, Vol. 13, p. 101, (1901).


D
T
R
C
P

were made air tight in the following way. Over C and P glass plates were cemented by means of the rubber preparation ordinarily used for making stop-cocks air tight. The window F was closed by means of a circular fluorite plate about 2 cms. in diameter and 2 mms. thick. This plate was placed between rubber washers, which had been previously smeared with the rubber preparation, and lowered into place at the inner end of a metal tube extending almost to the centre of the case. A brass ring was then screwed down so as to hold the plate in place and secure an airtight fit. The dome D was held in place by the same rubber preparation, and cemented to the glass connecting tube with Khotinsky cement. The rate of leak of the entire system, which contained besides these openings two stopcocks, amounted to about .003 mm. in 24 hours, which is not large considering the number of possibilities for leakage.

The Suspension. - The suspension was made in the following way; a very thin rod of glass about 3 centimeters long carried a cross arm near its upper end. To the extremities of this arm were cemented, by menas of hard shellac, rectangular mica vanes covered with lamp black.

The lower end of the vertical rod carried a small mirror placed at right angles to the plane of the vanes. A diagram and the exact dimensions of this suspension are given below.

m n = 32 millimeters.

Vane on the right of the diagram.

Length = .5313 cm.

Width = .0685 cm. (mean)

<u>Area</u> = 3.637 sq. mm.

Vane on the left of the diagram.

Length = .5305 cm.

Width = .0687 cm. (mean)

<u>Area</u> = 3.641 sq. mm.

ab (outside measurements) = .5401 cm

cd " " = .5427 "

Mean = .5414 cm.

1/2 x .5414 = .2707 cm.

OH (measured) .2728 cm.

Size of mirror 3 x 3 sq. mm.

Total weight 6 3/4 mg.

A quartz fiber attached the suspension to the torsion head.

<u>Sensitiveness</u>.

In the radiometer it is well known that there is a

critical pressure at which the sensitiveness is a maximum. The accompanying curve shows the relation existing between sensibility and pressure for the instrument under consideration. Abscissae are pressures, ordinates deflections. In plotting this curve there was used a 76 volt direct current Nernst filament supplied by a storage battery with a constant current of 0.32 of an ampere.

At the time the observations were made the battery was being used for no other purpose. It will be observed that the maximum sensibility falls at about 0.15 of a millimeter. This critical pressure varies greatly in different instruments. Values ranging from .05 mm in Nichols' radiometer to 0.15 mm in this case, are to be found. It has been suggested that the McLeod gauges which have been used to measure the pressure are responsible for the discrepancy.

The sensitiveness was also tested by means of a paraffin candle in order to compare it with that of other instruments of a similar construction. The three radiometers compared in the following table are, Radiometer used by Nichols * at the Yerkes in 1900. One used by Stewart** at

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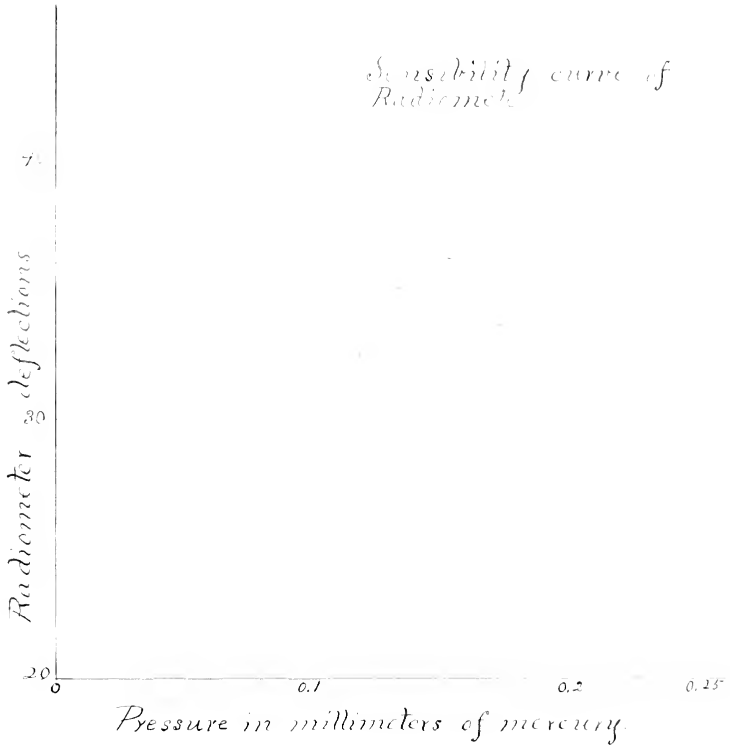
* E. F. Nichols, l.c.
** Physical Review, 13, p. 263, (1901).



Sensibility curve of Radiometer

Cornell in 1901. Radiometer used in this investigation. The deflections have been reduced so that the numbers correspond to deflections on a scale one meter from the mirror due to a candle one meter from the vane.

Comparison of sensibilities of various radiometers.

Comparison source - a paraffin candle.

By whom constructed.	Vanes.	Area of vane in sq. mm.	Deflection. Candle & scale 1 m off.	Deflection per sq. mm.	Relative sensibilities.	Time required for max. def. in sec.
Nichols.	Mica.	3.14	395	126	1.0	5.5
Stewart.	Platinum.	30	1467	49	0.4	40
"	Mica.	30			1.5	300
Porter.	Mica.	3.64	1000	275	2.0	45

Difficulties.

The difficulties met with in working with a radiometer have several times been enumerated, but a few words with reference to them in the present case may not be out of place. In general troubles arise from four sources; namely, (1) unsteadiness of the zero position, (2) mechanical jarring, (3) leakage of the radiometer case and connections and (4) static charges on the vanes. Leakage and charges on the vanes gave

practically no trouble after the instrument was finally gotten into working condition. The rate of leak as has been seen was too small to be in the least annoying, and the size of the vanes permitted them to be placed at such a distance from the fluorite window that, while still fulfilling the conditions of sensitiveness, they could turn completely round without striking against it and consequently becoming charged as frequently happens in the case of larger suspensions.

Unsteadiness of the zero position has given far more trouble. In so sensitive an instrument it is to be expected that such a difficulty will arise. This variation of the zero in the radiometer may be reduced in two ways; (1) by care in the construction of the suspension and (2) by guarding against irregular distribution of the radient energy reflected from objects situated obliquely in front of the fluorite window.

If the suspension were perfectly symmetrical with reference to the axis of rotation, any source of radiation, no matter how intense, to which the vanes are equally exposed, should produce no effect. It is, however, not possible to secure perfect symmetry , therefore deflections

may arise due either to the unequal absorption of radient energy by the vanes, or to inequality in the length of the two arms, or to both these causes combined.

Furthermore, the vanes are located at the inner end of a comparatively long tube, consequently, if the objects situated obliquely in front of this tube radiate unequally it is possible that both vanes may not be at the same time exposed to the action of equal forces. There will therefore result a rotation. This difficulty may be overcome by resorting to screens which will assist in securing a uniform distribution of the energy in the neighborhood of the radiometer. The figures given above give some idea in regard to thr symmetry of the suspension and the diagram of the apparatus shows the positions of the sheet iron screens about the radiometer.

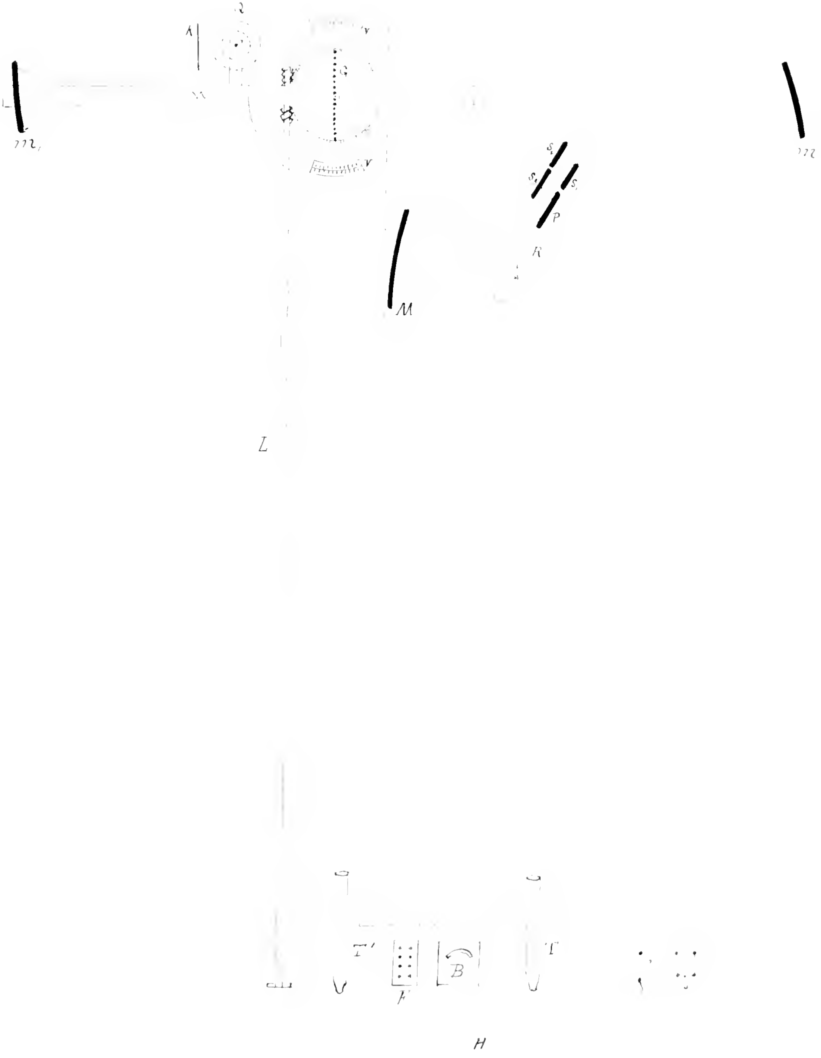
The source of the greatest annoyance has been mechanical jarring. The radiometer as well as other parts of the apparatus was supported upon marble slabs resting upon iron bars built into the wall of the laboratory. Nevertheless it was impossible to make observations during the day time. In the experiments on the Reststrahlen the readings were all taken between the hours of 8 and 12 P.M.

when there was no other person in the building. Even under these conditions much time was lost in waiting for the effects of passing cabs to subside. I have found that when perfect quiet is obtained the deflections of this instrument are entirely reliable to one tenth of a millimeter on a scale one meter off.

The spectrometer. - The divided circle used is one which has been employed in this laboratory for testing small plane gratings. This circle was set upon a heavy iron base and a steel arm so mounted that it, together with the circle, could be rotated in a horizontal plane about an axis passing through the centre of the circle. This arm carried three things; (1) a small concave mirror 52 cm radius of curvature, made by Bausch and Lomb, (2) a Nernst filament, the ballast being placed on the wall, and (3) a wire grating so mounted that the axis of rotation lay in the plane of the wires. The second mirror of the spectrometer which was of the same size and make as the one mentioned above was fixed. The arrangement of the apparatus is shown by the diagram on the following page which represents a horizontal section.

The letters indicate the following;

A spectrometer table.


Q
A
V
G
V
m_1
m
S_1
S_1
S_1
P
R
M
L
T'
F
B
T
H

n Nernst filament,

Q sheet iron screens,

W steel bar,

m m silver on glass concave mirrors ,

G grating,

K movable screen operated by a string in the hand of the observer at H,

V, V' verniers,

S slit,

S, S, S, surface under consideration,

M large silver on glass concave mirror.

R radiometer.

C and D switches in the incandescent lamp circuits.

F a resistance box,

L a brass rod by means of which the bar W can be turned about O.

T a telescope for reading the radiometer deflections.

T' a telescope for reading the vernier.

B an ammeter indicating the strength of the current through the Nernst filament,

I a sheet iron screen surrounding the radiometer and mirror.

P a plane silver on glass mirror.

The large mirror M was made by Bausch and Lomb, and has

a diameter of 12 cm and a radius of curvature of 26 cm. All the mirrors used were very good.

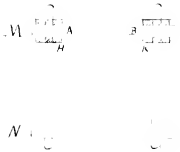
In order to read the vernier V by means of the telescope T' a small plane mirror was mounted above it making an angle of 45° to the vertical. A minature incandescent lamp, which could be turned on and off by means of a switch near the observer at H, illuminated the scale and vernier. It can be seen from the arrangement of the apparatus that while taking a series of readings it is entirely unnecessary for the observer at H to change his position and this rarely occurred.

The source.- The source was a 76 volt .44 of an ampere direct current Nernst filament supplied by a storage battery, which while readings were being taken was in use for no other purpose save for supplying the 14 volt incandescent lamps which illuminated the scale and vernier. These, as a rule, were kept burning continuously during a series of observations.

The source circuit contained in series a resistance box and milliammeter so placed that the current could be watched, and if necessary controlled, while readings were being taken without the observer moving from position.

The current variation was very small, never exceeding a hundredth of an ampere and frequently absolutely no change in the reading of the ammeter could be detected.

The grating.- The grating was made in a way similar to that described by Rubens and DuBois in Naturw . Rundsch. 8, (No. 36) 1893. A heavy brass frame, represented in



the diagram, was placed in a lathe, the ends of two wires of as nearly the same diameter as possible soldered at A, and wound under tension about M and N. After perhaps five centimeters of the length of the frame had been covered in this way the wires were soldered at B and the whole stretched by means of nuts H and K provided for the purpose. One of the wires was then cut and carefully unwound, while the remaining one was made fast to the brass pieces M and N by depositing electrolytically upon them a comparatively heavy coating of copper. This done the wire on one side was cut away. The spacings between the wires of a grating made in this way are very nearly equal to the diameter of the wire. The grating constant was determined by means of a divid-

ing engine as follows. A setting was made on the edge of each wire and the value of each space determined for the whole grating. The mean of these values was then averaged with the value of the constant found by taking the first and last readings and dividing the difference between them by the number of spaces. The value of the constant for the grating used in the wavelength determination was found to be 0.2414 of a millimeter.

Adjustments were made in the following way. After having first placed the grating G so that the plane of the wires included the prolongation of the axis of rotation, as nearly as this direction could be determined, the mirror m was moved along W until the reflected beam became parallel, then rotated about a vertical axis until normal incidence upon the grating was secured. By means of m_2 the spectrum was brought to a focus in the plane of the slit S. These adjustments having been made it was then only necessary to turn the rod L in order to bring any desired portion of the spectrum upon the slit. If the slightest change in the angle of deviation was to be indicated by the radiometer, it was necessary that the image of the filament and the slit S should have exactly the same width, and

since the mirrors m_1 and m_2 had the same focal lengths, S had to have a width equal to the diameter of the filament in order to secure this result. This width was generally slightly less than one millimeter.

As soon as the current begins to flow through a Nernst filament the filament twists out of its original position. Observation however showod that after the current was once started and the filament adjusted parallel to the slit there was no relative shift of the image and slit during a series of observations.

The surfaces S_1 S_2 S_3, supported on comparatively heavy iron blocks, resting on a wodden platform, were placed at about the angle represented in the diagram, no special care, however, being taken to secure accuracy in this respect. The mirror M focused the image of the filament on the radiometer vane which was slightly smaller than the image itself.

The method of measurement is this; note the spectrometer reading when the central image is focused on the vane, pass the spectra across the slit by turning L and if the surfaces show selective reflection for a particular wave-length, the deflections of the radiometer will rise to a maximum as that portion of the spectrum falls on the

slit. The difference between the spectrometer readings in the two cases is the angular deviation. The sine of this angle times the grating constant, if the spectrum be the first order, gives the wave-length.

Before making any new measurements it was thought best to repeat some which had already been made. For this purpose four quartz plates 4 x 4 cm. were placed at the points indicated in the diagram. The sensibility of the radiometer was such that the aperture of the mirror m had to be reduced considerably in order to bring the deflections within the range of the scale. The value of the wavelength determined from the position of the first maxima was 8.14 μ . Since this value was much too low according to the measurements of Rubens and Nichols, and since no special care had been exercised in procuring normal incidence upon the grating, the adjustments were all made again in as careful a manner as possible. The mirror m, was moved until the diameter of the beam reflected across the room remained constant. In order to secure normal incidence a long narrow mirror with the silvered side next to the wires was placed carefully on the grating

above the portion which was being used, and the mirror m, turned about a vertical axis until the reflected image of the filament lay in the prolongation of the filament itself. The wires of the grating and slit S were arranged parallel to each other by means of a fine silk thread plumb line viewed through a telescope. The filament was then adjusted parallel to S. These adjustments were of course all made after the spectrometer table had been leveled. The quartz surfaces were then put in place, and the positions of the first maxima on either side of the central image determined as follows. The observer at H moved the spectrum across the slit S by turning the rod L until he was sure he had passed beyond the position of the maximum in the Ist order spectrum. L was then turned slowly in the reverse direction as the observer watched the action of the radiometer through the telescope T. When it became evident that the maximum was approaching the slit of the spectrometer the screen K was lowered and when the steady conditions were reached K was raised and the deflection noted . K was then again lowered and another setting made, and so on until the first spectrum on the opposite side of the central image was reached. In the

neighborhood of the position of maximum deflection settings at every minute of arc on the spectrometer were made, care being taken always to make the setting by turning L in the same direction. In order not to bias the judgment no differences between spectrometer readings were taken until the observations were completed. Regarding the position of the central image as the zero on the spectrometer the positions of the maxima were on the one side 1° -58' on the other 1° -58'. For a grating constant equal to .2414 mm the value of the wavelength for this angle is 8.28μ. Although two different gratings and four different sources namely; a Nernst filament 110 V. A.C., a Nernst filament 76 V. D.C., a Welsbach mantle and a hot platinum wire have been used I have been totally unable to obtain a value higher than this. It is with some hesitation that I give these results, my only excuse being that I have sought diligently for a source of error and have been able to find none. Objection might be raised to the use of a Nernst filament without a slit. To this it seems only necessary to say that the value of the wavelength obtained when the filament was replaced by a Welsbach and slit was 8.25μ. Frequently after having determined the positions of the three maxima i. e., the first order on the left, the cen-

tral image and the first order on the right, the spectra were again shifted across the slit and the positions of the three maxima again determined, with the same result within the limits of error of observation, thus always showing that the apparatus underwent no change during a series of observations.

Aschkinass (Annalen 65, p. 241, (1898) has found that marble (white) reflects strongly in the neighborhood of wavelength 6.7μ which value he obtained by the method of Reststrahlen. The value I have obtained for white marble is 6.77μ.

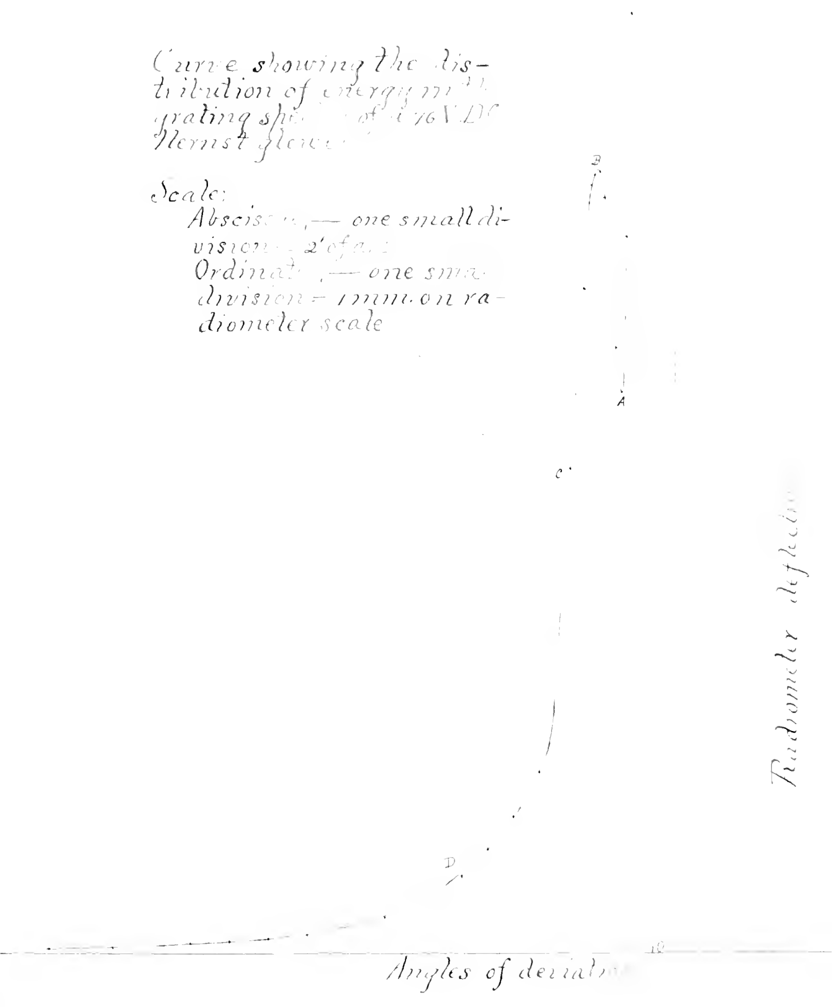
The remainder of this paper will be devoted to a consideration of substances whose Reststrahlen have not been determined before. It was not possible to cut the crystals with any reference to the optic axis, nor does this seem necessary, for the experiments with quartz have shown that the phenomena are independent of the direction in which the faces are cut. Furthermore owing to the small size of the crystals the number of surfaces used has been uniformly only three.

Potassium dichromate. - Crystals of this substance readily take a high polish. In area the surfaces obtained varied from three to six square centimeters. The curve is plotted

in the way usually employed in measurements of this kind with spectrometer readings as abscissae and deflections of the radiometer as ordinates. The curve is therefore symmetrical about the maximum deflection corresponding to the central image.

In order to make clear the meaning of this as well as the curves that follow, I have added another which shows the distribution of the energy from a 76 V. D.C. Nernst glower in the grating spectra, from the central image out beyond 10μ in the first order spectrum. This curve was obtained by substituting for S_1 S_2 S_3 silver on glass mirrors. The maximum deflection in the central image is not given because it was too large to be read on the scale, notwithstanding the fact that the aperture of the mirror m_1 was cut down to the size of a pin head. ABCD shows the energy distribution in the first order spectrum. B is the point of maximum emission of energy from the source. Its angle of deviation is approximately 20' which corresponds to a wavelength $\lambda = 1.4\mu$. Assuming the law $\lambda_m \theta$ = const., we getfor the temperature of the glower 2062° C. Abs.

In all the curves which follow we find these emission maxima on either side of the central image. An examination



Curve showing the distribution of energy in grating spectrum of a 76 V DC Nernst glower

Scale:
Abscissa,— one small division = 2' of arc
Ordinates,— one small division = 1 mm. on radiometer scale

of the curves, however, will show that there is some variation in their position relative to the central image. This shifting may be due to several causes. In the first place the current through the filament was not the same for any two curves, and in the second, if the substance should possess any strong reflecting power in the neighborhood of this maximum, the result would be an apparent shifting of the energy maximum, in either one direction or the other.

We will return to the consideration of the potassium dichromate curve. D and E, then, are the maxima due solely to the energy emission of the source. By increasing the number of surfaces these could doubtless be cut out as was found to be the case with quartz. With three quartz surfaces these maxima occur in approximately the same position as in all the curves here given, but by increasing the number of surfaces to four they disappear, although the curve slopes off gradually at the base on either side of the central image and does not fall to zero abruptly as does the one given by Rubens and Nichols for four surfaces. The cause of this difference is undoubtedly to be found in the greater sensitiveness of the instrument used in this work. A and C are the first order spectra of the waves

Curve showing the selective reflection of Potassium Dichromate.

Scale:

Abscissae — one small division = 2' of arc

Ordinates — one small division = 1mm on radiometer scale

most strongly reflected by the substance, or what has been termed the Reststrahlen. In comparing this curve with the energy curve of the source it is to be remembered that the aperture of the mirror m_1 in this case was the total aperture, while in the case of the energy curve obtained with the silver mirrors it was not over a millimeter

The angles of deviation of A and C are 2° - 28' and 2° - 26' respectively. The wavelength corresponding to 2° - 27' is 10.31 μ.

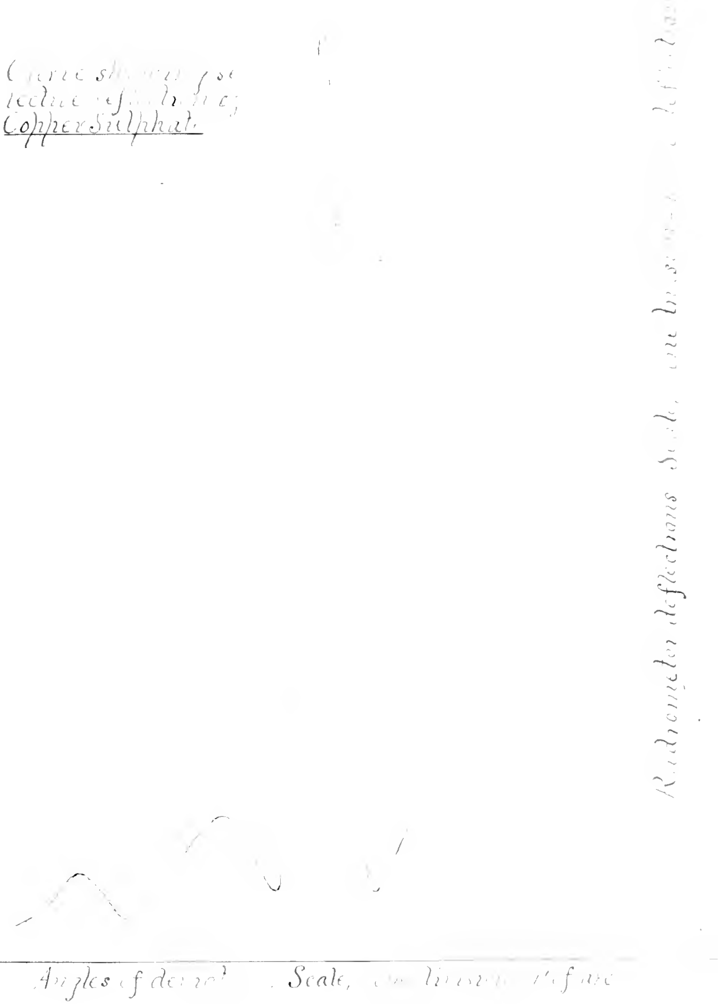
Copper Sulphate.

The quality and size of these surfaces were similar to those of the dichromate. The curve presents the same peculiarities only appearing different because of the difference in the scales to which the two are drawn.

Positions of the maxima.

Energy maxima	18′ 1/2 and 20′ 1/2
Reststrahlen maxima	47′ 1/2 and 46′ 1/2

The wavelength corresponding to 47′ is 2,30 μ.



Curve showing [illegible] value of [illegible] Copper Sulphate

Tartaric Acid.

The reflecting surfaces obtained in this case were exceptionally good, but the areas of the surfaces were very small, not over 3 sq. cm. for the largest S_3.

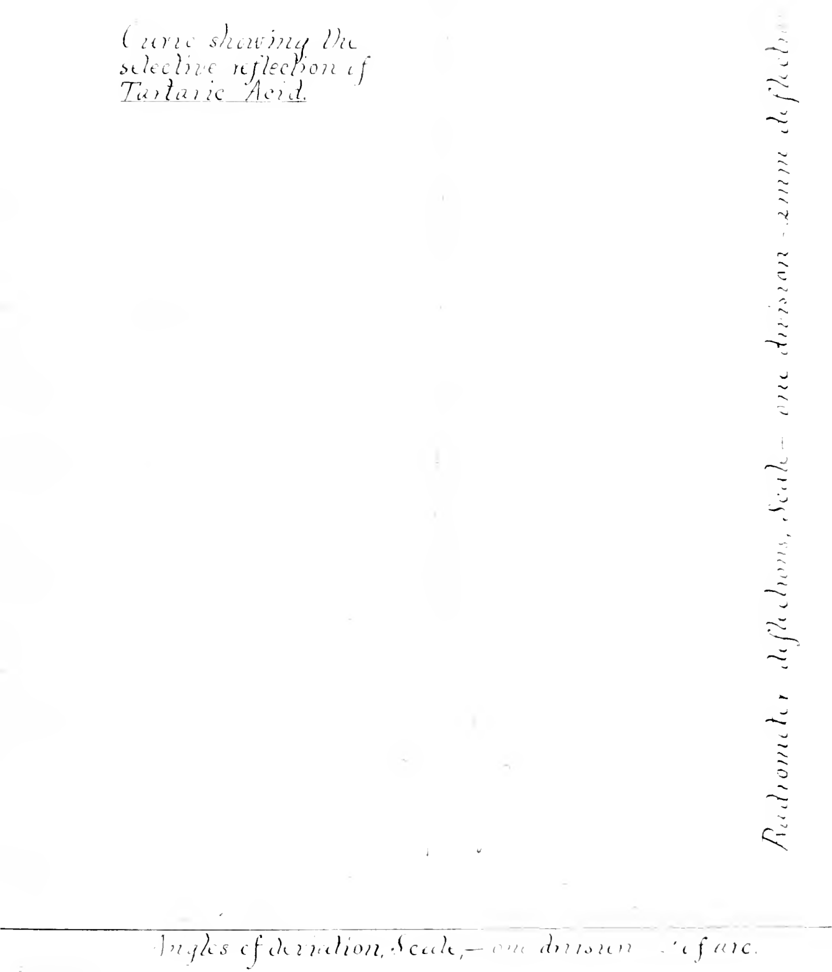
Positions of the maxima.

Energy maxima, 19' and 20'

Reststrahlen maxima, $1^\circ - 21'$ and $1^\circ - 22'$.

Wavelength corresponding to $1^\circ - 21'1/2'$ is $5.72\,\mu$.

Curve showing the selective reflection of Tartaric Acid.



Ammonium Chloride

The surfaces of ammonium chloride were not so good, but were much larger than in the above cases.

Position of the maxima.

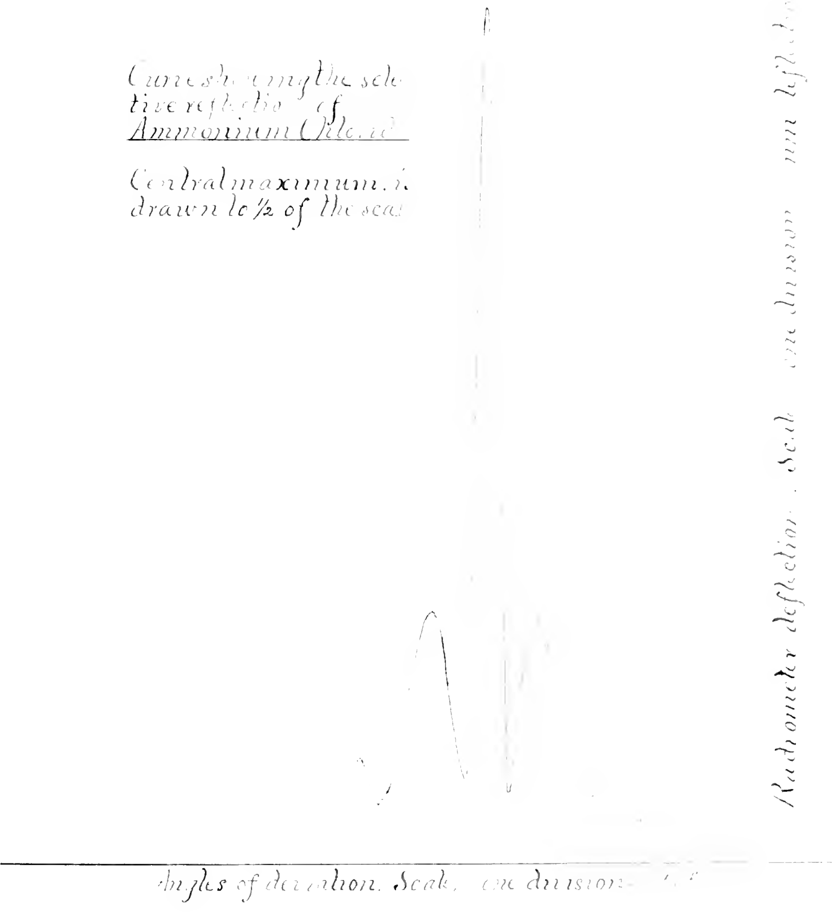
Energy maxima 19' and 21'

Reststrahlen maxima 47' and 48'

Wavelength corresponding to 47 1/2' is 3.44μ .

Curve showing the selective reflection of Ammonium Chloride

Central maximum is drawn to ½ of the scale



Potassium Sulphate.

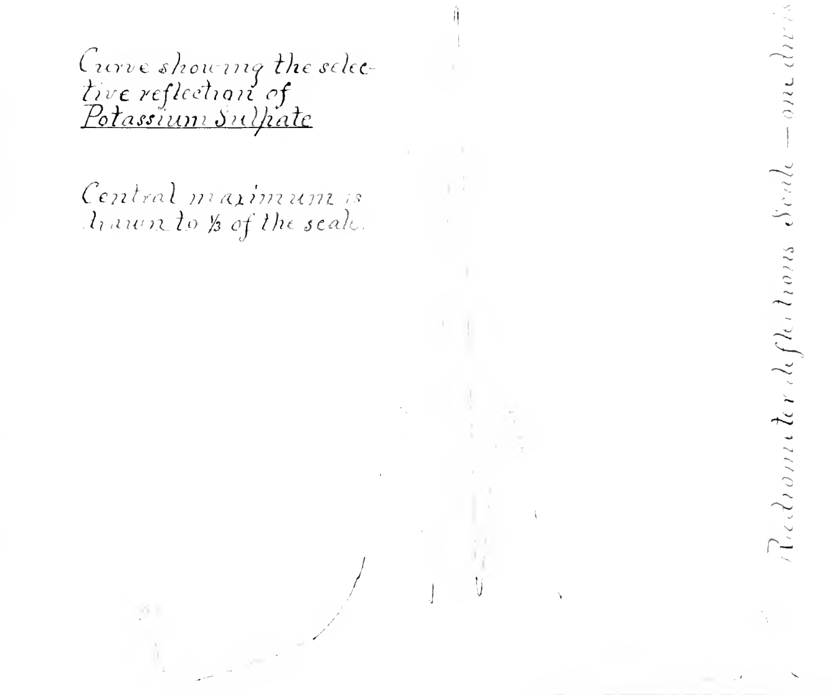
Large crystals of this substance were not at my disposal. Aggregates of small ones, however, were found which were so compact that surfaces were readily polished on them. Although the surfaces obtained in this way were somewhat discontinuous the amount of energy reflected was amply sufficient for the measurements. The area of the largest was not over 4 sq. cm.

Positions of the maxima.

Energy maxima, 21' and 21'

Reststrahlen maxima, 2° - and 2°

Wavelength corresponding to 2° is 8,42 μ.



Curve showing the selective reflection of <u>Potassium Sulphate</u>

Central maximum is drawn to ⅓ of the scale.

Potassium Bisulphite.

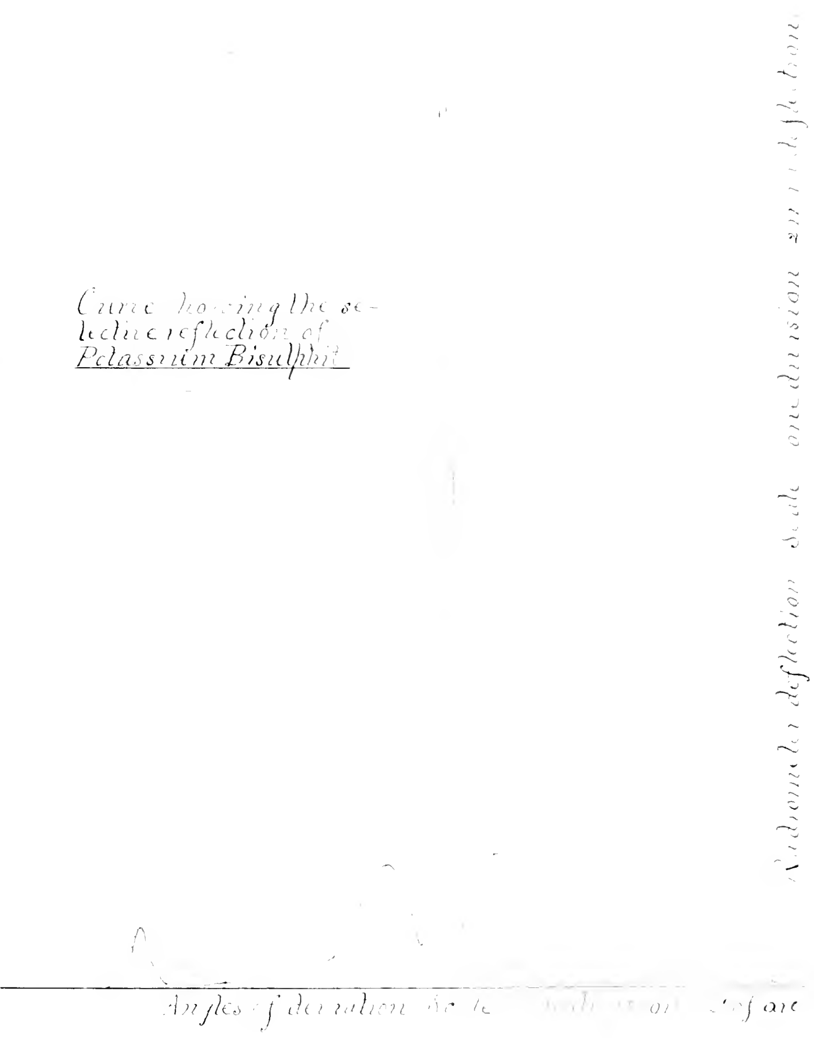
These surfaces were also obtained by polishing aggregates of small crystals as in the last case.

Positions of the maxima.

Energy maxima, 20' and 21' 1/2

Reststrahlen maxima, 1° - 56' and 1° - 58'

Wavelength corresponding to 1° - 57' is 8.21μ.



Curve showing the selective reflection of Potassium Bisulphite

Potassium ferrocyanide.

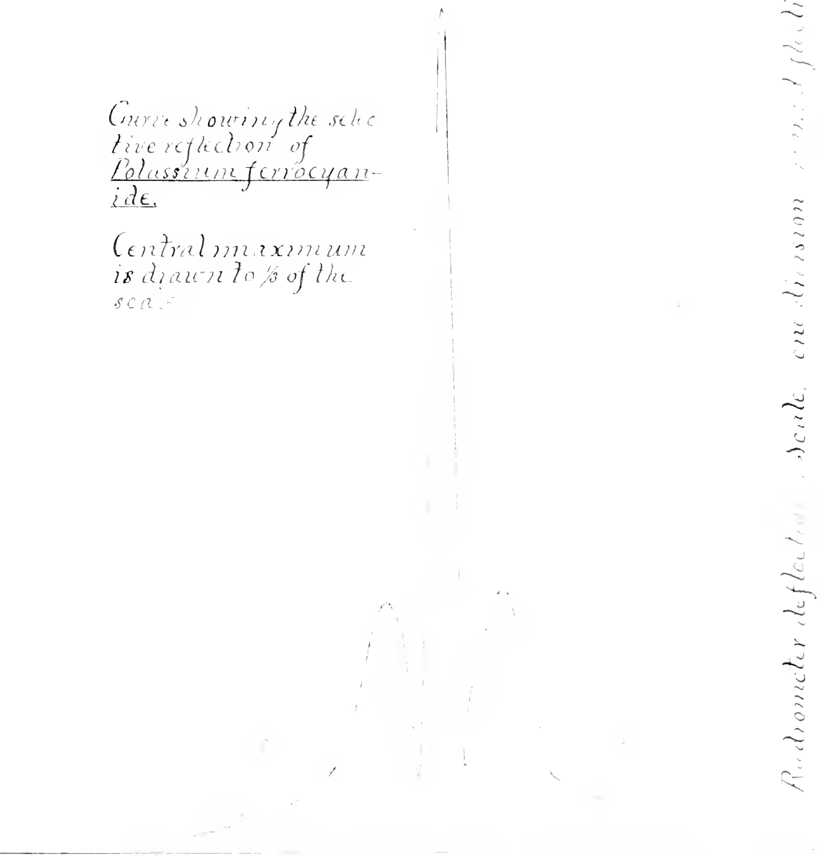
The somewhat cheesy nature of potassium ferrocyanide rendered it difficult to obtain surfaces of sufficient reflecting power. Success was finally obtained and the accompanying curve shows the results.

Positions of the maxima.

Energy maxima, 22' and 24'.

Reststrahlen maxima, $1^\circ - 9'$ and $1^\circ - 9'$.

Wavelength corresponding to $1^\circ - 9'$ is 4.84μ.



Curve showing the selective reflection of Potassium ferrocyanide.

Central maximum is drawn to ⅓ of the scale.

Summary of Results.

Wavelengths of the Reststrahlen from various substances below 11μ determined from measurements on Ist order spectra.

Substance	Source	Wavelength
Quartz	76V.D.C.Nernst Filament	8.28 μ
Marble(white)	" " "	6.77 μ
Potassium dichromate	110A.C.Nernst Filament	10.31 μ
Copper sulphate	" " "	2.30 μ
Tartaric acid	76 V.D.C. " "	5.72 μ
Ammonium chloride	" " "	3.44 μ
Potassium sulphate	" " "	8.42 μ
Potassium bisulphite	" " "	8.21 μ
Potassium ferrocyanide	" " "	4.84 μ

The following table giving the substances whose Reststrahlen have been determined by others is added for the sake of completeness.

Substance	By whom measured	Wavelengths in μ.
Quartz	Rubens and Nichols	8.50, 9.02, 20.75
Mica	" "	9.20, 18.40, 21.25
Fluorite	" "	24.4
Rock Salt	Rubens and Aschkinass	51.2
Sylvine	" "	61.1
Marble	Aschkinass	6.69, 29.4

Before concluding I wish to say a few words in regard to some experiments which have been made with a view to determining whether or not the waves in the neighborhood of 8.5 μ can be elliptically polarized by reflection from a quartz surface. The fact that one is compelled to keep both the source and the radiometer in fixed positions has rendered the necessary adjustments very difficult. For polarizer and analyzer I have used two

small fluorite plates about 2 1/2 centimeters square. At this wavelength fluorite reflects only about 2% of the energy incident upon it, consequently, by the time the radiations have suffered reflection at two fluorite and three quartz surfaces there is very little energy left at one's disposal. Although I have not succeeded in carrying out the experiment to a definite conclusion the preliminary tests have shown that the radiometer is sufficiently sensitive to detect the small quantity of energy with which one has to deal. I therefore hope to obtain some results which will be conclusive on this point.

To Professor Joseph S. Ames, under whose direction this work has been done, I am greatly indebted, chiefly for his valuable suggestions and his unfailing interest.

BIOGRAPHICAL SKETCH,

James Temple Porter was born in Bath County, Virginia, September 29, 1873. At the age of 13 he entered the preparatory department of St. Johns College, Annapolis, Md. In the fall of 1891 after having been out of school for a year and a half he matriculated at Randolph-Macon College, Ashland, Virginia, from which institution he received the degree of Bachelor of Arts in June 1895. The two following years were spent, one as instructor in Martha Washington College, Abingdon, Va. and the other as instructor in Randolph-Macon Academy, Front Royal, Va. In the fall of 1897 he returned to Randolph-Macon College as a student, and in June 1898 was admitted to the degree of Master of Arts. From September 1898 to June 1901 he was again instructor in Randolph-Macon Academy. In October 1901 he entered Johns Hopkins University where, during the past four years, he has as a graduate student in the department of Physics attended courses under Professors Ames, Wood and Bliss and Associate Professors

Whitehead and Cohen. From 1901 to 1903 he held a Virginia scholarship, from 1903-1904 a position as Student Assistant in Physics, and during the present session has held a Fellowship in the same department.